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A SUBMERSIBLE PUMP SUSPENSION SYSTEM

Cross-Reference to Related Application

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States Provisional Application(s) listed below:

Application Number: 60/262161

Filing Date: January 17th, 2001

BACKGROUND OF THE INVENTION

Technical Field of the Invention

Suspension systems, submersible pumps, submersible pumps suspension systems.

Description of the Background Art

Sub A1 The invention of the electrically actuated submersible pump by Armais Arutunoff in 1933 started an era where electrical power replaced mechanical force as the method used to transmit the necessary power to downhole pumps for the extraction of various materials. Since the Arutunoff invention, methods have been improved to take advantage of the unique characteristics of the pump and power source. The most significant improvement was the dramatic reduction in the mass and size of the elements used to transmit the power and to react the resulting forces. For example, steel rods were replaced with much lighter electrical cable and heavy production tubing once required to react mechanical actuation was replaced with much lighter production tubing.

The successful installation of an electrical submersible pump in a well usually requires that the following three steps and/or functions take place. The first step is the

suspension of the mass of the production string either from the wellhead or the casing. The production string is everything inside the casing below the wellhead, and typically includes the production tubing, the fluid inside the production tubing and the electrical cable. Secondly, there must be proper conveyance of the pumped fluid from the pump to the surface, typically through a closed tube. Finally, electrical power must be conveyed from the surface to the pump. For example, modern electrical submersible pumps are installed in drilled wells that have been cased with steel pipe, and have installed inside the casing production tubing that consists of 30 foot sections of 2 inch production tubing that are screwed together to form a continuous pipe. Attached to the production tubing is a multi-conductor electrical cable used to provide power to the pump. The electrical cable is typically banded to the production tubing every 10 feet, and is installed outside the production tubing. Two of the required functions are accomplished by the production tubing, namely suspension of the mass and conveyance of the pumped fluid. The third function, conveyance of electrical power, is accomplished by electrical cable banded to the production tubing.

Numerous attempts have been made to improve conventional practice by combining two or three of these functions into a single structure that can be spooled on a reel and played continuously into the well. The advantages are obvious. Lighter (hence cheaper) structures can be obtained by this combination, and easier installation is the result of a continuous structure that can be conveniently transported and deployed into the well from a reel. Another significant advantage is the ability to quickly and easily remove the pump for maintenance. As early as 1968, the inventor of the submersible centrifugal pump, Armais Arutunoff recognized the above-mentioned advantages and in US patent 3,411,454 he proposed a flexible cable that consisted of strong steel fibers interwoven with electrical

conductors to form a cable that provides both electrical power and load suspension. An additional structure, a liner, was used to convey fluids from the pump to the surface. Because the pump was located inside the liner, the pump could be installed and replaced without removing the liner, thus providing most of the advantages of combination.

Variations of this theme, commonly referred to as cable suspended pumping systems or CSPS, were pursued for the next 20 years. The most significant problem was the tendency of the electrical cable and the mechanical cable to be incompatible under mechanical load. This lead to persistent failures of many design variations until the mechanical cable was separated from the electrical cable and loosely attached as in US patent 4,681,169. This allowed load to be transferred from the electrical cable to the steel cable, but did not tightly tie the two together, which had been the problem with other CSPS cables. This approach did not address the conveyance of fluids from the pump to the surface that was presumably accomplished with a conventional liner.

With the introduction of coiled production tubing, the load suspension element was changed from wire rope to coiled production tubing, and many variations of combinations of coiled production tubing and electrical cable were patented. US patent 5,906,242 illustrates a typical system, where upon the coiled production tubing bears the weight of the pump and electrical cable. Both coiled production tubing and flexible steel cable combined with electrical cable accomplished the suspension and electrical power conveyance functions, but required that an additional function, namely fluid conveyance to the surface, be accomplished by another structure, normally a liner.

US patent 5,180,014 takes the ideas of US patent 5,906,242 further by strapping the electrical cable to the outside of the coiled production tubing, and using the coiled production tubing to both suspend the load and convey the pumped fluid. This approach

assumes that the coiled production tubing has sufficient strength to support the weight of the production tubing, pumped fluid and electrical cable, which is often the case when using steel production tubing, but is not the case when non-metal production tubing is used. Steel coiled production tubing, while continuous and somewhat flexible, has the disadvantage of requiring heavy bending and straightening equipment when installed from a reel into a well. Flexible, non-metallic production tubing has the advantage of not requiring any bending or straightening equipment, and can simply be installed directly from the reel. In common practice, metallic coiled production tubing, and the apparatus needed to install it in the well, are too complex and expensive to be used in most oil and gas wells. When lower strength, more flexible production tubing (typically non-metallic production tubing) is used, the cost is reduced, and far less equipment and expense are required when the well is pulled. Because of its lower tensile strength this type of production tubing cannot support the suspension loads, therefore, an additional support member is needed. The case where lower tensile strength-flexible production tubing is used as the production tubing is addressed by this application.

Other innovators took a different approach. Instead of combining two of the three functions, they sought to accomplish all three functions in a single unit. US patent 4,830,113 uses coiled production tubing with the electrical cable inside to accomplish all three functions. US patent 4,336,415 takes a different approach, namely placing the electrical cable and suspension cable outside a core of flexible production tubing. All methods must address a fundamental problem associated with CSPS, namely mechanical incompatibility under load, by adding complexity such as a spiral tubing lay to counteract the tendency of a combined cable to fail under mechanical load.

Few, if any, of these combined structures are in common use today for two reasons that are addressed by this application. First, a combined structure is much more expensive than its component parts, especially when the component parts are available as commodities. Wire rope, high pressure production tubing and electrical cable are built for many industries in footages many times the footage used in the oil industry. This economy of scales dramatically reduces the price per foot. When these elements are combined and additional design features, such as a spiral lay, are added to address the incompatibility problem, a special cable is needed at an expense which is many times more than the cost of the individual elements.

The second drawback is the inability to change the individual elements. This would come into play when part of the structure is damaged, or needs to be changed in response to an individual installation. For example, if electrical damage necessitates the replacement of the electrical cable, the entire assembly would need to be replaced. If a deep well with a low flow rate is fitted with an all in one cable, a non-optimized pipe size or electrical conductor size would be used, or many variations of the cable would be needed.

SUMMARY OF THE INVENTION

A single structure to accomplish the suspension of a submersible pump and all associated loads, the conveyance of the pumped fluid from the pump to the surface, and the conveyance of electrical power from the surface to the submersible pump is disclosed. The system comprises three individual elements that are assembled just before installation into the casing and are immediately disassembled when removed from the casing: a mechanical suspension means to bear the mechanical loads, a flexible tubular conduit to convey the fluid from the pump to the surface, and an electrical cable to convey electrical power from the

surface to the pump. A method to quickly and economically assemble and disassemble these elements as they are installed or removed from the casing is also disclosed.

Sub A3 ~~The mechanical suspension means comprises a continuous~~ length of flexible cable, that can be made of metallic or non-metallic materials, formed into a long cylinder or rope and spooled unto a round reel that allow the cable to be played off the reel into the well continuously. Alternatively, to take advantage of readily available materials found in oil and gas fields, sucker rods, which are inflexible rods made of metallic or non-metallic materials, may be used as the mechanical suspension means. Although not as convenient as flexible cable, they may be preferred in specific situations for cost and availability reasons. The mechanical suspension means is the primary load bearing member and the other members are attached to it and loads are transferred from the other members to the suspension cable either continuously ~~or at periodic intervals.~~

The production tubing is used to convey fluids from the submersible pump to the surface, and must have sufficient strength to withstand the pressure of the pumped fluid. The weight of the production tubing and the pumped fluid is transferred to the mechanical suspension means, so the axial strength of the production tubing can be relatively low, allowing it to be made of a lightweight, flexible, low cost material such as plastic.

The electrical cable is used to convey electrical power from the surface to the submersible pump and may be armored or unarmored. The cable is typically insulated with a plastic material, and is attached to the suspension cable either continuously or at intervals to transfer the weight of the electrical cable to the mechanical suspension means.

Sub A4 ~~The disclosed invention has three major advantages over the prior art.~~ First, all elements are available in bulk reels, or readily available, eliminating the need to produce a custom cable. Second, as the elements are installed, they are attached together,

Sub A4 ~~accomplishing the transfer of weight from the electrical cable and the~~ production tubing to the mechanical suspension means. Because the elements are not rigidly attached, they can stretch at different rates, without affecting each other significantly. This accomplishes the transfer of mechanical loads from the electrical cable and the production tubing to the mechanical suspension means while simultaneously eliminating the tendency of CSPS cable to fail mechanically under load. Third, all elements are inherently flexible, or in the case of rigid sucker rods, they can break down to convenient lengths, and can be separated when removed from the well. When combined at the wellhead, the resulting suspension system can be lowered and removed continuously, and when out of the well the individual elements of the suspension system can be automatically stored on separate reels or racks. Also, because all elements are modular and commonly used in wells, they can be installed and removed easily, with a minimum of specialized equipment to facilitate repairs to the submersible pump.

Several methods can be used to attach the mechanical suspension means, the production tubing and the electrical cable as the pump is installed in the well. To attach continuously and automatically, various forms of a jacket can be used. These jackets are continuous lengths of material that are wrapped or continuously clamped to the elements as they are installed to transfer the mechanical loads to the mechanical suspension means. The jacket must be installed tightly enough to transfer the loads, but not so tightly as to create interaction problems between the elements. A non-metallic tape, made of a resilient material that is wrapped in a spiral pattern automatically as the pump is installed has been used successfully for this purpose.

Sub A5 ~~To attach periodically, conventional clamps,~~ similar to those used to clamp electrical cable to production tubing in a conventional installation ~~are used. These~~ clamps can be

Sub A5 made from a variety of materials including plastic, metal or rubber. The clamps wrap around the three elements, binding them together at a single point. A one piece clamp, consisting of a metal band tightened by a gear driven clamp that is lined with rubber is the preferred method. The clamps are typically installed at 30 foot intervals.

To install the pump in the well, the mechanical suspension means, electrical cable, and the production tubing are attached to the submersible pump. The pump is suspended over the well by the mechanical suspension means, and the electrical cable and production tubing are attached to the mechanical suspension means starting immediately above the pump. The pump is lowered into the well by playing out the mechanical suspension means, the electrical cable and the production tubing at the same rate from appropriate reels. The mechanical suspension means, because it is under significant load, must be played out with appropriate mechanical controls to lower and lift the assembly in a controlled manner. Many commercially available cable and rod control systems exist for this purpose. The electrical cable and the production tubing may be reeled onto their respective reels manually or by a powered commercial reel spooling device.

As the pump is lowered, the clamps are installed either continuously or at periodic intervals. The attachment of the clamps can be accomplished manually (by hand) or automatically (by machine). When the pump is at the appropriate depth, the mechanical suspension means is tied off to the wellhead, suspending the load in service. Alternatively, a packer can be deployed (by pressure or mechanically) to lock the pump at the appropriate level. For convenience when pulling the assembly, a breakout plug is installed at the lower end of the production tubing. The electrical cable and production tubing are attached to wellhead penetrators and then to the appropriate systems outside the well.

SubA6]

~~Description of the Several Views of the Drawings~~

Figure 1 is a cross sectional view of a typical well as the submersible pump suspension system is installed. Figure 2 is a cross sectional view of a typical wellhead after the submersible pump suspension system is installed, showing the attachment of the mechanical suspension means, production tubing and electrical power cable. Figure 3 is a section of the production string, showing the attachment of the mechanical suspension means, production tubing and the electrical power cable.

Referring to figure 1. a well casing 1, extends into the ground into a producing zone, where a submersible pump 2, is located. The submersible pump 2, is connected to a mechanical suspension means, 3 that supports the weight of the pump, and suspends the submersible pump 2. The upper end of the mechanical suspension means, 3 is connected to a wench 4, located on truck 5. The wench 4, is capable of providing the necessary tension on mechanical suspension means 3, to safely raise and lower the submersible pump 2. The mechanical suspension means 3, is directed from the wench 4, into the well casing 1, by a pulley, 10. The pulley 10 is rigidly connected to truck 5. The height of the pulley, 10 is sufficient to allow the submersible pump 2 to be directed into the well casing, 1. Production tubing 8, is played off of reel 9 and redirected by pulley 11 into the vicinity of mechanical suspension means, 3. Similarly, electrical cable 6 is played off reel 7 and redirected by pulley 11 into the vicinity of mechanical suspension means 3.

Referring to figure 3, when the mechanical suspension means, 3, the production tubing, 8, and the electrical cable, 6, are about to enter or exit the casing, 1, clamp 18 is installed or removed at intervals, typically 10-30 feet. The clamp 18, bind the mechanical suspension means, 3, the production tubing, 8, and the electrical cable, 6, allowing the

transfer of weight from the electrical cable, 6, and the production tubing 8, to the mechanical suspension means, 3.

Referring to figure 2, once the submersible pump is lowered to the appropriate level and the installation is completed, the mechanical suspension means, 3, is attached to the wellhead 13 through hook 12. The production tubing is terminated at the wellhead 13, and passes through the wellhead via penetrator 15 and out tube 16. The electrical cable is terminated at the wellhead 13, and passes through the wellhead via penetrator, 14, and connects to electrical cable 17.

~~Description of the Preferred Embodiment of the Invention~~

The preferred embodiment of the disclosed invention comprises the following three elements. The mechanical suspension means, in this example a suspension cable, made of stainless or carbon steel (stainless is preferred) of a standard wire rope construction, sufficiently sized to bear its own weight, the weight of the pumped fluid, the weight of the electrical cable and the weight of the production tubing and clamps. The suspension cable is provided on a reel that is capable of being used with a commercial cable wench. Many sizes, strengths and flexibilities are available from manufacturers and the selection should be guided by good engineering practice. Alternatively, a rod string of sufficient size may be used in place of the suspension cable as the mechanical suspension means. In this case, a conventional pull and run rig is used to control the descent and ascent of the rod string.

The second element is plastic production tubing, also provided on a reel. The tubing is made of a plastic material and has sufficient wall strength to withstand the bottom hole pressure generated by the pump. Areoquip model FC372 is an example of a plastic production tubing, with plastic fiber reinforcement suitable for this application. This

production tubing is capable of producing wells up to 7500 feet deep and up to a temperature of 200 F, but many other production tubing products, reinforced or not reinforced are also suitable. The inside diameter of the production tubing must be sized to provide a low pressure drop over the depth produced, and is sized based on the fluid pumped, the flow rate and depth of the well. In this example, .75 inch inside diameter production tubing is used.

The third element is the electrical power cable. This cable normally consists of round copper conductors, solid or stranded, insulated by a plastic material. The insulated conductors are formed into a round or flat configuration, and are covered with an additional plastic jacket which may be covered in metal armor. For this example, three number 12 copper conductors are insulated with cross linked polyethylene, formed into a round configuration, and jacketed with an additional layer of cross linked polyethylene. The size of the conductors selected depends on the horsepower of the motor and the depth that are determined by well known engineering practice. This electrical power cable is also provided on a reel.

The three elements are sized and specified according to the practice outlined above and delivered on reels to the well site. In the preferred embodiment, the suspension cable reel is fitted to a commercial wench that is capable of generating tensile forces to control the ascent or descend of the assembly on the cable as the cable is inserted or withdrawn from the well. In addition, a boom with a pulley is provided to redirect the path of the cable downward, into the well casing. The submersible pump is attached to the cable and lowered into the top end of the well casing. The other two elements, the electrical cable and the production tubing are connected to the appropriate ports on the submersible pump. The suspension cable, the electrical cable and the production tubing are attached to each other

at the top of the pump. In this preferred embodiment, a rubber lined gear clamp is used to bind the elements together. Alternatively, an automatic spiral rubber tape can be used to automatically and continuously bind the elements together.

The submersible pump with the suspension cable, production tubing and electrical cable are then lowered into the well. At periodic intervals, (or continuously) the elements are bound together using clamps. When the pump is at the appropriate depth, the suspension cable is tied to the well head and transfers the mechanical load through the wellhead to the casing. Alternatively, a packer may be used to directly transfer the pump load to the casing. The electrical cable is attached to an electrical feed-through in the wellhead, and the production tubing likewise is attached to a fluid feed-through, both of which allow the electrical power cable and production tubing respectively to exit the well through the wellhead.

If it should become necessary to remove the pump for repair, the removal procedure is essentially the reverse of the installation procedure. The elements are disassembled at the surface and then stored on reels or racks for later reuse. The clamps are removed to be reused, or in the case of continuous tape, can be slit automatically and discarded.